

Commitment
to Safety

**Evolution
of Airplane
Interiors**

Replacing Halon:
A Progress Report

Fire Protection:
Passenger Cabin

Equipping a
Fleet for Required
Navigation
Performance

AERO

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AERO

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Commitment to Safety

At Boeing, our commitment to safety is at the very core of all we do. We have the privilege of working with you, our valued customers, to enhance the safety, efficiency, and reliability of your fleet.

That same working-together spirit is at the heart of aviation's commitment to safety. Together, manufacturers, airline operators, government regulatory and investigative authorities, airport operators, and others — in short, our entire industry — work to maximize safety by sharing data, aligning resources, and addressing risks together.

In this issue, we offer a prime example: the evolution of airplane interiors.

When you configure your airplane interiors, you make a series of choices to balance your marketing and operational needs along with passenger preferences. It is an opportunity for you to brand your product and services.

Part of feeling comfortable in an airplane interior is feeling safe. Today's airplane interiors reflect decades of innovation and effort toward safer, more survivable interiors.

Thank you for your commitment to safety and for your business with Boeing.



CORKY TOWNSEND
Director, Aviation Safety
Boeing Commercial Airplanes



Ongoing work with regulators has resulted in interiors that are designed to increase the survivability of accidents that occur during takeoff or landing.

Aviation Safety: Evolution of Airplane Interiors

Accidents involving the current generation of commercial airplanes are rare but offer important insights into advancements in the safety and crashworthiness of airplane design. These advancements reflect decades of innovation and targeted efforts to improve survivability in an airplane accident, especially during takeoffs and landings.

By **Alan J. Anderson**, Payloads Engineering Chief Engineer (Retired), Interiors-Payloads System Engineering

The accident fatality rate for jet airplanes has fallen dramatically during the last 50 years. This decrease is due in part to continuing efforts by airplane manufacturers and regulators to use information gained from accidents to develop safer, more survivable airplanes.

This article provides examples of significant interior enhancements to Boeing airplanes and how they enhance airplane safety, particularly during accidents that occur during takeoffs and landings.

A HISTORY OF IMPROVING AIRPLANE INTERIORS

Since the first passenger airplane was introduced in the 1930s, airplane manufacturers have worked to make airplanes safer for the passengers and crew who fly in them (see fig. 1). For example, Boeing has worked continuously to enhance the safety of its products and to lead the industry to higher levels of safety through global collaboration.

By working together, regulators, operators, and manufacturers can maximize safety by sharing knowledge and targeting safety efforts to address areas with the most risk.

Some recent events highlight the safety of today's passenger jet airplane interiors during takeoff and landing accidents.

- In December 2008, an airplane crashed while taking off, ending up on fire in a 40-foot-deep ravine several hundred yards from the runway. There were no fatalities among the 115 passengers and crew, even though the metal fuselage had been breached by fire.
- In December 2009, an airplane carrying 154 passengers and crew overran the runway during a landing in heavy rain and broke apart. There were no fatalities.

Figure 1: Airplane interiors over time

Boeing airplane interiors have become both more comfortable and safer over time.



Boeing 247 (1933)



Boeing 707 (1958)



Boeing 787 (2011)

- In August 2010, an airplane crashed while attempting to land during poor weather, breaking into three pieces on impact. There were 125 survivors among the 127 passengers and crew aboard the flight.

The industry's work on airplane safety and survivability of airplane interiors emphasizes three areas: surviving impact, surviving a fire, and evacuation.

SURVIVING IMPACT

Survivability is greatly influenced by seat design. The greater the ability of airplane seats to remain in place and absorb energy during an impact, the greater the likelihood of passenger survival. In addition, the seat back is designed to protect passengers behind the seat from head injury.

Seat design. In the 1930s, passenger airplane seats could withstand a static force six times the force of gravity (6g). For commercial jet airplanes beginning in the 1950s, the 6g requirement was raised to 9g. Today's seats are required to withstand a 16g dynamic force. A 16g seat is tested in a manner that simulates the loads that

could be expected in an impact-survivable accident. Two separate dynamic tests are conducted to simulate two different accident scenarios: one in which the forces are predominantly in the vertical downward direction and one in which the forces are predominantly in the longitudinal forward direction. The highest load factor is in the forward direction at a force of 16g.

Head injury protection. Where head contact with seats or other structure can occur, Boeing provides protection so that the head impact does not exceed the head injury criterion (HIC) established by the U.S. Federal Aviation Administration (FAA). HIC measures the likelihood of head injury resulting from an impact. Compliance with the HIC limit is demonstrated during a dynamic sled test that includes a 50 percent male-size test dummy, the seat, and any airplane structure that could be impacted by the occupant's head.

SURVIVING A FIRE

In 1985, the FAA developed a new test standard for large surface area panels, such as ceilings, walls, overhead bins, and partitions. The standard required that all

commercial airplanes produced after August 20, 1988, utilize panels that exhibit reduced heat and smoke emissions, delaying the onset of a flashover (i.e., the simultaneous or near-simultaneous ignition of all flammable material in an enclosed area). Interiors are updated and refurbished many times during the life of an airplane. This results in interiors that incorporate these enhancements even in older airplanes.

In addition, airplanes manufactured on or after August 20, 1990, must comply with definitive standards of a maximum peak heat release rate of 65 kilowatts per square meter, a maximum total heat release of 65 kilowatt minutes per square meter, and specific optical smoke density of 200 (i.e., the OSU 65/65/200 fire safety standard defined by Ohio State University).

Extensive fire protection systems are also part of every Boeing passenger airplane. These systems include the use of fire-protective materials, smoke detection and fire extinguishing systems, and insulation blankets designed to resist burn-through from a fuel fire next to the bottom half of the fuselage. (For more information on passenger compartment fire protection, see page 19.)

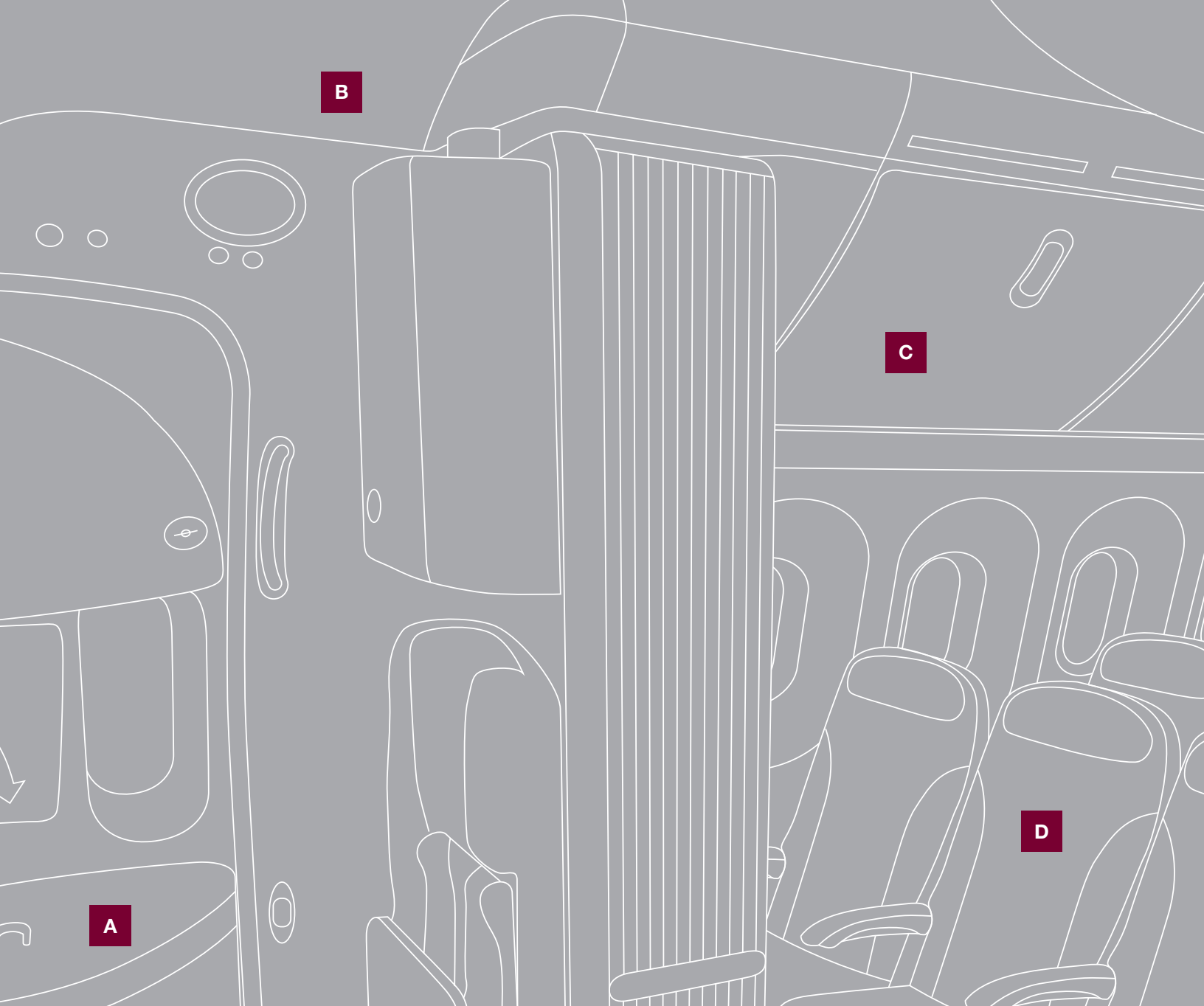


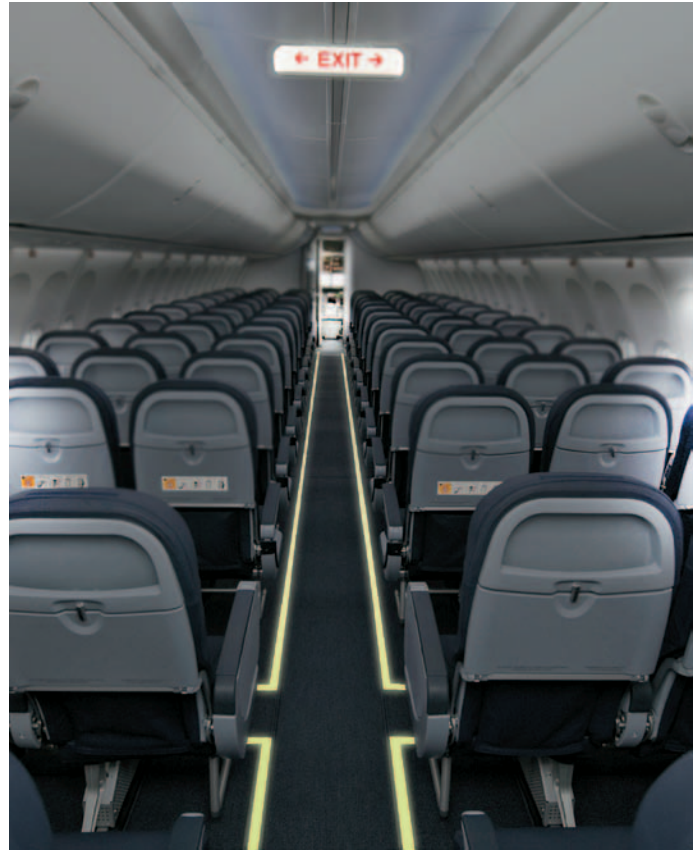
Figure 2: Design features key to rapid evacuation

Because evacuating an airplane quickly greatly increases survivability rates, all Boeing airplanes include a number of features designed to enable evacuation within 90 seconds.

- A** Escape slides help passengers evacuate the airplane quickly.
- B** Fire-retardant insulation slows down the burn-through of a fire outside the airplane into the cabin.
- C** Fire-retardant materials are used on cabin sidewalls, stowbins, and stowage compartments.
- D** Fire-blocking covering and fire-retardant materials are used over seat cushions.
- E** Fire-retardant materials are used on carpets.
- F** Emergency proximity lighting leads passengers toward exits in smoke-filled cabins.

Figure 3: Floor proximity lighting

Floor proximity lighting aids airplane evacuation under dark or smoky conditions.



EVACUATING THE AIRPLANE

The FAA requires that an airplane can be evacuated of all passengers in 90 seconds. Boeing airplane interiors include a number of features to facilitate this process (see fig. 2). These features include floor proximity lighting and escape slides.


Floor proximity lighting. When passengers evacuate after a crash, buoyant hot smoke and gases can fill the cabin down to near floor level, obscuring overhead lighting. Evacuation is improved through the use of lights, reflectors, or other devices to mark the emergency escape path along the floor. The FAA determined that floor lighting could

improve the evacuation rate by 20 percent under certain conditions. As a result, the U.S. commercial fleet was retrofitted with floor proximity lighting by 1986, marking the completion of a two-year compliance schedule (see fig. 3). The 777 was the first Boeing airplane to include floor proximity lighting in production models.

Escape slides. Boeing passenger airplanes are equipped with automatic, self-inflating slides that are made of fire-resistant materials that become rigid after being deployed. (For information about the evolution of escape slides, see page 10.)

SUMMARY

Boeing has worked with regulators, operators, and industry to continually enhance the safety of its airplanes. This ongoing work has resulted in interiors that are designed to increase the survivability of crashes that occur during takeoff or landing.

For more information, please contact Air Safety Investigation at airsafetyinvestigation@boeing.com. 

The evolution of the escape slide: A case study in innovation

Boeing and other airplane manufacturers are continually improving airplane safety by using information gained from accidents and by applying new technologies. The evolution of the escape slide is an excellent case in point.

The handheld fabric chute came into use on passenger airplanes in the 1940s. It used essentially the same approach as the fabric slides used to evacuate burning buildings in the 19th century.

Inflatable escape slides became available about the same time as the early jet-powered airplanes were entering the final design stages in the United States in 1957. These slides used a tube-on-tube design, with the evacuee sliding on a large center tube with two side-rail tubes, an approach that greatly advanced safety standards. Because of the physical bulk of the escape slide system, it was not practical to locate the equipment anywhere except above the ceiling. As a result, deployment of these early slides was relatively difficult, requiring five separate operations to reposition the slide from the ceiling to the floor so it could be inflated — all after the door was opened. Ten to 20 seconds were required to deploy the slide and 15 to 18 seconds were required to inflate the slide, for a total of 25 to 38 seconds.

DECREASING DEPLOYMENT TIME

The next major change in escape slide design occurred around 1960 with the introduction of slides with two parallel tube members with a sliding surface suspended between the tubes. A head tube at the top provided support and stability at the upper end of the slide, a toe-end tube provided ground support, and a cross-tube maintained side-tube separation. These new slides included a metal girt bar that allowed the slide to be attached to the airplane floor, a girt consisting of a fabric panel between the girt bar and the head tube to secure the slide to the airplane, and a manual inflation handle on the girt to manually inflate the escape slide.

By 1963, improvements in materials and inflation systems reduced the weight and bulk of the slide system, making it practical to move the slides out of the ceiling to the lower inboard face of the cabin doors (see fig. A). This location resulted in a still more efficient escape system, reducing the time needed to ready an escape slide from between 20 to 50 seconds to between 18 and 24 seconds, including door opening time.

Further improvements in the efficiency of the aspirators that inflate the slides reduced inflation times to as few as six seconds by 1966. Detachable girts made it possible to detach the inflated escape slide from the airplane in a ditching situation to serve as a supplemental flotation device.

Automatic inflation of escape slides was introduced a couple of years later, providing yet another element of safety: Untrained passengers could now open a door and inflate the slide during an emergency. Later, automatic escape slides became a requirement at all floor-level exits.

By the last half of the 1960s, development work began to incorporate the features of a raft into an escape slide. The first such units were put into operation in 1971. This technology provided further improvements in passenger safety and eliminated the need to carry and maintain separate rafts, unless they were needed to supplement the airplane's slide/rafts.

IMPROVEMENTS IN DEPLOYED SLIDES

Today's escape slides are designed to accommodate all airplane attitudes, taking into account all combinations of landing gear position, loss of any gear, and varying heights of different airplane models (see fig. B).

Materials used for slides resist burning and meet the latest radiant heat requirements. They are also resistant to fluids, food contamination, and exposure to sun. Door slides must inflate within 10 seconds after initiation of deployment, and off-wing slides must inflate within 15 seconds. They must be capable of supporting 60 persons per sliding lane per minute. And they must also be capable of being deployed into 25-knot winds from any direction.

TESTING ENSURES PERFORMANCE

An extensive test program is carried out by both the escape slide manufacturer and the airframe manufacturer to ensure the escape slide system meets all performance requirements. This involves thousands of slide deployments and hundreds of live subjects.

Figure A: Door-mounted slide

Moving escape slides from above the ceiling to the doors greatly reduced the time required to ready the slide for evacuation.

For example, the 747 airplane slide development program for the main and upper-deck doors involved more than 6,300 inflations and 40,000 live subjects. Recent programs have used high-fidelity test modules manufactured by suppliers to Boeing's specifications to test, retest, qualify, and certify escape slide systems. Typical tests include:

- Fabric tensile and tear tests under normal conditions and when exposed to fluids and accelerated aging.
- Fabric permeability tests.
- Seam and adhesive peel and shear strength tests.
- Fabrics resistance to fungus, beverages, foods, and fluids including fuel, hydraulic and cleaning fluids, salt spray, sand and dust, humidity, and atmospheric pressure changes.
- Simulated rainfall to ensure that the sliding characteristics of a wet slide are adequate and safe.
- Burst pressure tests.
- Lifecycle tests to 40 cycles.
- Beam strength tests to confirm the maximum number of occupants that can be supported by the slide without buckling.
- Centrifuge tests to assure that the escape slide system as a whole can meet maximum g-loads as required by the U.S. Federal Aviation Administration.
- Environmental tests to account for the environmental extremes of high and low temperatures to which the airplane will be subjected.
- Full-scale evacuations with live subjects to demonstrate that the maximum number of passengers the airplane can carry can be safely evacuated in 90 seconds with only half the exits available.

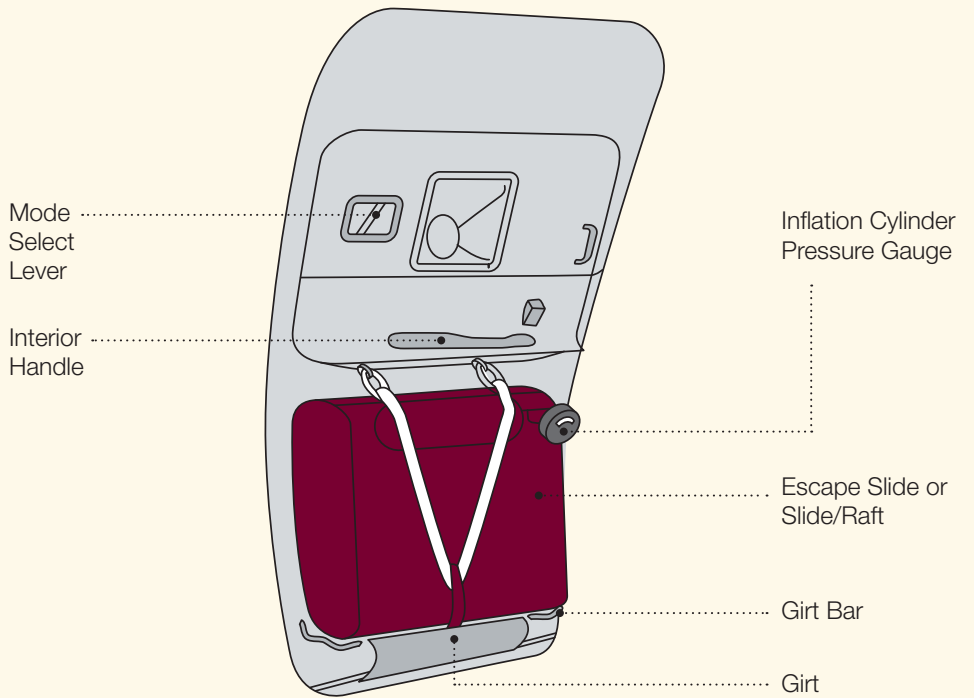
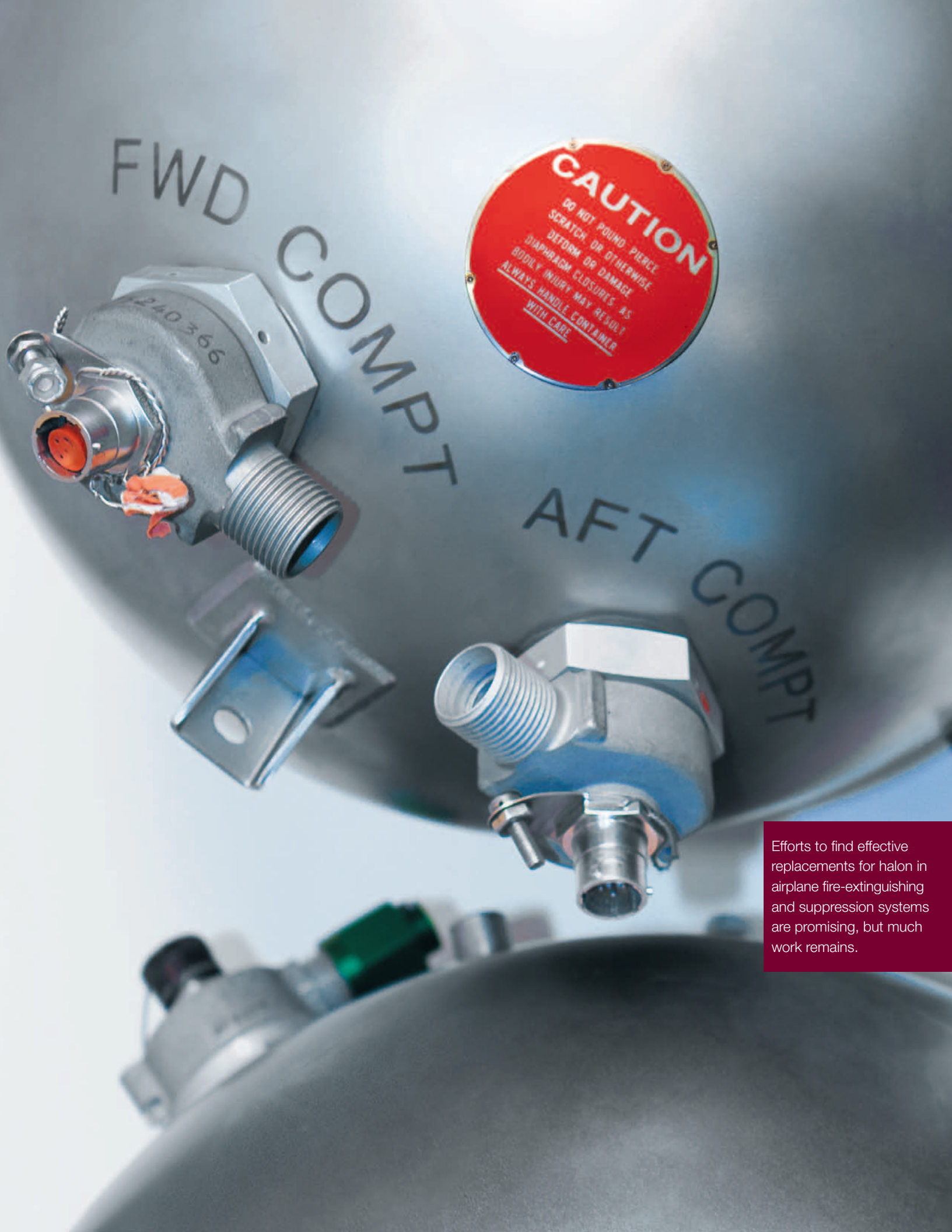


Figure B: Upper-deck slide

Slides inflate and extend to the ground automatically from varying airplane heights and attitudes. They are made with fire-resistant materials and remain rigid after being deployed.





FWD

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CAUTION
DO NOT POUND, PIERCE,
SCRATCH, OR OTHERWISE
DEFORM OR DAMAGE
DIAPHRAGM CLOSURES, AS
BODILY INJURY MAY RESULT.
ALWAYS HANDLE CONTAINER
WITH CARE.

240 366

Efforts to find effective replacements for halon in airplane fire-extinguishing and suppression systems are promising, but much work remains.

Replacing Halon in Fire Protection Systems: A Progress Report

The aerospace industry has been working to find effective replacements for halon in airplane fire-extinguishing and suppression systems since production of the chemical was banned in 1994. Industry has conducted extensive research on halon alternatives, but fully replacing the chemical will require multiple regulatory approvals and the cooperation of all stakeholders.

By Robin Bennett, Hazardous Materials Leader, Product Development, Environmental Performance Strategy

In 1994, halon production ceased in developed countries after scientific evidence suggested that halon contributes to the depletion of the stratospheric ozone layer. While potential replacement chemicals have been proposed, none of them meet all of the stringent performance requirements for aviation. As a result, the industry relies on recycled halon to meet current needs. The European Union adopted halon replacement deadlines for airplanes in 2010 while the International Civil Aeronautic Organization (ICAO) established halon replacement deadlines in 2011.

This article summarizes current progress on the replacement of halon for fire extinguishing and suppression on board commercial airplanes in engines, auxiliary

power units (APUs), cargo compartments, handheld fire extinguishers, and lavatories.

HOW HALON BECAME THE INDUSTRY STANDARD

In the 1960s, the fire protection industry began installing a new and very effective agent for use in fire extinguishers and protection systems. The agent, a class of chemicals known as halon, extinguishes and suppresses a wide variety of fires, including flammable liquids, electronics, and common combustibles. Halon is ideal for use around airplane structure and equipment because it is noncorrosive and nonconductive, and it leaves no residue.

Moreover, because it is so effective in small quantities, halon is considered safe for use in human-occupied spaces such as passenger cabins and flight decks.

By the 1980s, the scientific community had identified halon as an ozone-depleting substance (ODS), similar to Freon and other chlorofluorocarbons (CFCs). CFCs are very effective, versatile, and stable chemicals. However, their stability is a detriment because their long lifetime allows them to migrate to the upper atmosphere where ultraviolet light triggers a chemical reaction that may cause depletion of the stratospheric ozone layer.

In 1987, the Montreal Protocol, an international treaty, established the production phaseout and use reduction of CFCs.

Figure 1: Halon replacement deadlines

In 2010, the European Commission adopted cutoff and end dates for essential-use exemptions for halon on airplanes operating in the European Union. The International Civil Aviation Organization adopted halon replacement deadlines in 2011, and Underwriters Laboratories will withdraw its standard for halon in handheld fire extinguishers in 2014.

	REQUIREMENT	LAVATORY	HANDHELD	PROPULSION/ AUXILIARY POWER UNIT	CARGO
New Design (New Type Certification Application)	European Commission Cutoff Date	2011	2014	2014	2018
	International Civil Aviation Organization	2011	2016	2014	N/A
	Underwriters Laboratories Standard	N/A	2014	N/A	N/A
Current Production	European Commission End Date*	2020	2025	2040	2040
	International Civil Aviation Organization	2011	2016	N/A	N/A
	Underwriters Laboratories Standard	N/A	2014	N/A	N/A

* Includes retrofit with non-halon agent

As part of the 1992 London amendment, halons were added to the agreement. Exemptions were provided for those applications where alternatives were not available that allowed “essential use” of the available ODSs. The aviation industry was exempt because none of the currently available alternative fire-extinguishing and suppression agents could meet the stringent performance requirements to ensure safety of flight. Since the Montreal Protocol, the aviation industry has continued to rely on recycled halon to sustain its current needs.

Recently, several organizations and agencies have reevaluated the continuation of the essential-use exemptions. In 2010, the European Commission amended its ODS regulation by adopting cutoff and end dates for essential-use exemptions on airplanes and other applications. A cutoff date applies to any new airplane model or major derivative upon submission of a type certification application. The end date is defined as the date after which halon shall not be used in all commercial airplanes, including the existing fleet. ICAO adopted halon replacement deadlines in 2011, and Underwriters Laboratories (UL) is withdrawing

its standard for halon-based handheld fire extinguishers in October 2014 (see fig. 1).

The aviation industry began researching halon alternatives more than 15 years ago. Because of stringent safety and engineering performance requirements, development and validation of alternatives on airplanes must meet many regulatory requirements for fire protection, including the U.S. Federal Aviation Administration (FAA) minimum performance standards (MPS) which demonstrate fire-extinguishing and suppression performance equivalent to or better than halon.

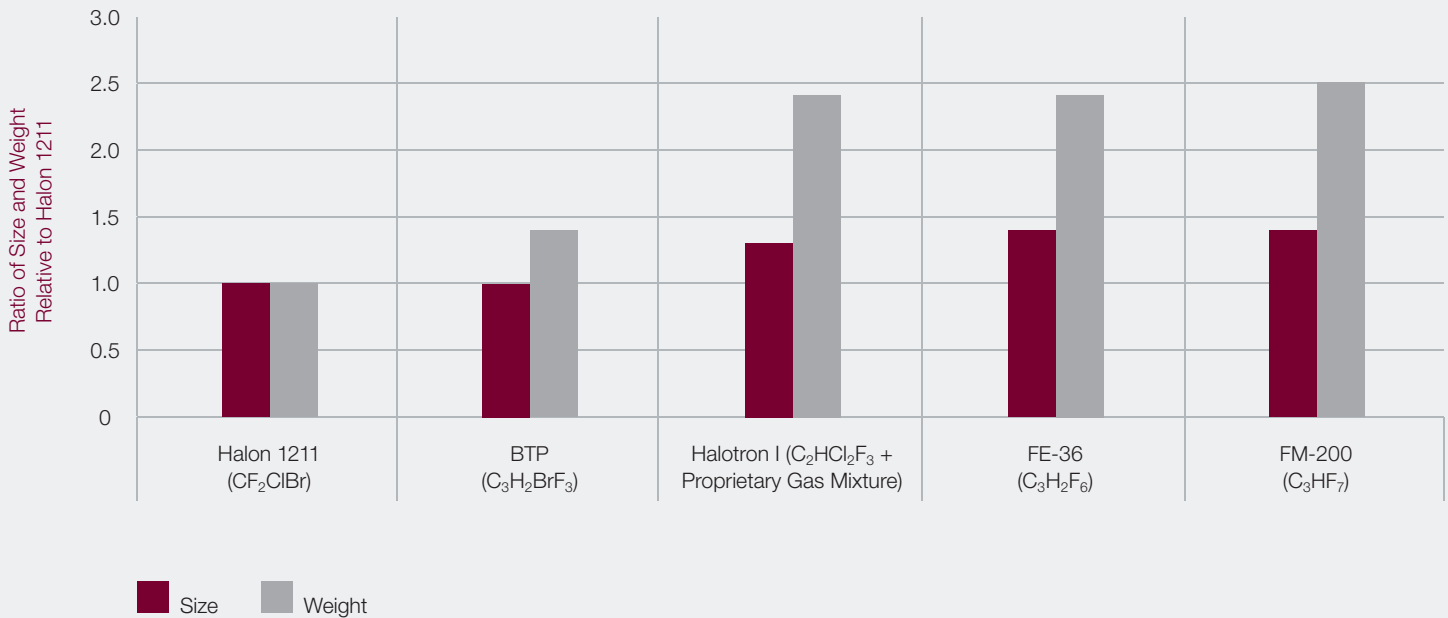
Alternative fire-extinguishing and suppression agents and extinguishing hardware must also be reliable and effective at extreme temperatures, at various altitudes, and under extreme vibration; be compatible with a wide range of materials and equipment, including electronics, fluids, composites, and metals; have toxicity equivalent to or less than halon; and are environmentally preferable. Some potential replacements are listed as greenhouse gases under the 1997 Kyoto Protocol, an international treaty on climate change. Their

use and production are being scrutinized and are likely to be restricted in the future.

In addition to agent requirements, the system for agent storage, distribution, and application must meet specific performance requirements. All fire protection system components for the alternative agents must be designed and demonstrated to function properly under all foreseeable operating conditions. Component qualification tests must ensure the component specification requirements are met. System certification tests ensure that a system performs its intended function per FAA requirements. System and component test procedures include system performance validation, environmental conditioning, structural integrity, and lifecycle testing. Operational requirements should be similar to halon systems (i.e., no significant increase in training or maintenance requirements and equivalent shelf and installation life). Finally, the system and its components must be of a size and weight that can be practically integrated into the airplane. This is particularly challenging because most of the agents with published FAA MPS concentration values require significant increases in mass

Figure 2: Comparison of handheld fire extinguisher size and weight

Extinguishers using other agents are nearly 50 percent larger and two and a half times heavier than Halon 1211 extinguishers. The size and weight of 2-bromotrifluoropropene (BTP) handheld fire extinguishers are very similar to that of Halon 1211 extinguishers.



and/or volume to provide performance equivalency to that of halon (see fig. 2).

HALON USE THROUGHOUT COMMERCIAL AIRPLANES

Halon is used to extinguish and suppress fires in four applications on commercial airplanes:

- Lavatory extinguisher bottles (Halon 1301) installed in airplanes prior to 2007.
- Handheld fire extinguishers (Halon 1211) located throughout the cabin, flight deck, crew rest compartments, and accessible cargo compartments.
- Cargo compartments (Halon 1301).
- Engines and APUs (Halon 1301).

LAVATORY EXTINGUISHERS

The extinguishers mounted in lavatory trash receptacles (lavex) were the first to have an MPS defined in 1997.

Current status and next steps: Two agents passed the MPS tests in December 2000.

Production qualification testing of parts was completed in September 2002. The installation certification test plan for the lavex bottles was approved in October 2002. Following FAA approval of the installation testing and certification data and coordination with the bottle and lavatory suppliers, the non-halon lavex — HFC-227ea — became standard on all in-production Boeing airplanes with standard lavatory configurations by the end of 2006. Documentation to allow replacement of halon lavex bottles on older Boeing airplanes will be available through Boeing Commercial Aviation Services in early 2012. The implemented replacement, non-halon lavex agent HFC-227ea, is a hydrofluorocarbon (HFC), which is defined by the Kyoto Protocol as a greenhouse gas and may be subject to future restrictions.

HANDHELD FIRE EXTINGUISHERS

The handheld fire extinguisher MPS was issued in August 2002 (see fig. 4). It specifies two tests that replacement agents

must pass in addition to requiring national certification, such as that provided by UL.

Current status and next steps: Of the seven potential fire-extinguishing agents evaluated, three passed the MPS and are UL approved: Halotron I (HCFC Blend B), FE-36 (HFC-236fa), and FM-200 (HFC-227ea). The bottles for these approved candidates are about one and a half times larger and two times heavier than the currently used UL-rated 5B:C Halon 1211 bottle (see fig. 2). Halotron I has a much lower ozone-depleting potential than Halon 1211, but its HCFC constituent is scheduled for a 2015 U.S. production ban, as mandated by the Montreal Protocol and the U.S. Clean Air Act, although recycled agents may be used after that date. The other two alternative agents, FE-36 and FM-200, have global warming potentials greater than Halon 1211 and are listed as greenhouse gases under the Kyoto Protocol. Their use and production are likely to be restricted in the future.

Replacement of existing Halon 1211 handheld fire extinguishers with these agents presents long-term financial

Figure 3: Comparison of fire-extinguishing and suppressing agents for engines

This chart compares agents with published concentration values to the FAA minimum performance standard for engines requiring significant increases in concentration (i.e., more agent) to demonstrate performance equivalency to that of halon. A challenge is presented to airframe manufacturers because any halon alternative system would be much larger and heavier, making integration into the airplane problematic.



and environmental costs. Implementation of these larger, heavier replacement bottles may require the relocation of extinguishers or adjoining emergency equipment, redesign of interior panel structure, and recertification of extinguisher installations for in-production airplanes and retrofit applications. The increased size and weight of the bottles may also hinder firefighting performance in an airplane cabin.

For the reasons stated above, Boeing is pursuing an alternative that is more compatible with existing airplane designs and airline operational requirements and will fulfill long-term environmental requirements. Boeing is sponsoring the development of 2-bromotrifluoropropene (BTP), which has successfully passed a series of tests and studies supporting FAA MPS, airplane material compatibility, and atmospheric environmental effects. BTP handheld fire extinguishers are similar in size and weight to current Halon 1211 extinguishers and have passed UL 711 5B performance tests. A toxicology testing program is under way. That program and subsequent government agency approvals could take two to three years, which aligns with the ICAO replacement dates.

Concurrently, the FAA has been working with the International Airplane Systems Fire Protection Working Group to address aviation industry concerns over alternative agent toxicity guidelines. The revised FAA Advisory Circular (AC) 20-42D redefines the method for determining agent toxicity concentrations, which means that use of some alternatives in small compartments will exceed the recommended concentrations. Supporting documentation for the calculation of stratification effects is pending release, upon completion of testing at the FAA. This documentation should increase the minimum safe volume requirements for halocarbon agents. Although intended only to provide guidance, AC 20-42D describes means of compliance considered acceptable to the FAA airplane certification offices.

ENGINE AND APU FIRE EXTINGUISHERS

The FAA Technical Center, in collaboration with the International Airplane Systems Fire Protection Working Group, developed an MPS for engines and APUs (see fig. 4). The

MPS includes minimum concentration requirements published for three agents — HFC-125, CF₃I, and Novec 1230. Because all of these agents are less effective than halon and require higher concentrations, airplane fire protection systems will be significantly heavier than halon and require more volume (see fig. 3). Some of these agents may also raise toxicity and global warming concerns by other organizations.

Current status and next steps: Boeing and a supplier have been working with the FAA Technical Center on a dry powder agent since 2007. However, in 2009, testing was suspended to revise the MPS to replace the halon baseline agent with a surrogate agent, HFC-125 (eliminating halon release during MPS testing), and to better accommodate nongaseous agents. In 2010, testing resumed and continued into 2011. Meanwhile Boeing has been discussing agent/system qualification and certification requirements with the FAA Aircraft Certification Office. Stakeholder acceptance (airlines, engine, and APU manufacturers) is another challenge to implementation yet to be resolved. Once an MPS concentration

Figure 4: Information sources on minimum performance standards for fire-extinguishing and suppressing agents

CATEGORY	MINIMUM PERFORMANCE STANDARD
Lavatory	http://www.fire.tc.faa.gov/systems/lavx/lavxmmps.stm
Handheld	http://www.fire.tc.faa.gov/pdf/01-37.pdf
Engines and Auxiliary Power Units	http://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf
Cargo	http://www.fire.tc.faa.gov/pdf/TN05-20.pdf

has been determined, Boeing will seek final approval of an airplane certification plan for the appropriate airplane models.

CARGO FIRE SUPPRESSION

The cargo MPS was last updated in June 2005 to incorporate FAA and industry comments (see fig. 4). It specifies four fire test scenarios that the replacement suppression agent must meet to demonstrate equivalent performance to Halon 1301: bulk-load fires, containerized-load fires, surface-burning fires, and aerosol-can explosions.

Current status and next steps: In late 2009, Boeing initiated a research effort with the National Institute of Standards and Technology and other collaborators to understand why several promising replacement agents have failed the aerosol-can explosion test and, under certain conditions, actually promote combustion. Understanding the problem will help determine a solution and ultimately a viable agent for use in cargo bays. Future plans include an expansion of the project to

collaborate with industry and other research institutions. Along these lines, the University of Maryland has been awarded a fellowship to join the NIST study, and two papers documenting initial results are slated to be published later this year.

As in the handheld agent replacement efforts, the following characteristics need to be factored into determining the best replacement: ozone depletion potential, global warming potential, atmospheric lifetime, toxicity, material compatibility, airplane operating environment, system complexity, maintenance, agent size and weight, and requirements for cleanup. The replacement must also meet the basic MPS established by the FAA.

Qualification and certification of a non-halon agent and fire suppression system will be more complex than the replacement of lavex extinguishers, and implementation on currently produced airplanes is several years in the future. Boeing is aggressively seeking replacement agents and systems from the fire protection industry. Like BTP, any promising agent will be investigated to understand its capabilities and viability.

SUMMARY

Efforts to find effective replacements for halon in airplane fire-extinguishing and suppression systems are promising, but much work remains for all stakeholders. Boeing continues to collaborate with industry groups and certification authorities to identify, certify, and implement halon replacements on its commercial airplanes.

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A comprehensive systems-level approach in cabin design minimizes fire potential and helps ensure passenger safety.

Fire Protection: Passenger Cabin

The cabins on all Boeing airplanes incorporate comprehensive fire-protective features and materials to minimize the potential for a fire and help ensure the safety of passengers.

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This article is the third in a series exploring the implementation of fire protection on transport category airplanes.

Two types of fires can affect an airplane and its occupants: in-flight and post-crash. An in-flight fire usually occurs as a result of a system or component failure or maintenance issue. A post-crash fire usually results from ignition of fuel released during a crash landing. Boeing considers both types of fires when designing for airplane cabin fire protection. Fire protection is one of the highest considerations at Boeing in airplane design, testing, and certification.

In designing an airplane's fire protection features, Boeing uses a systems-level

approach that goes beyond ensuring individual parts meet fire property requirements by looking at the integration of all those parts on the airplane. This approach uses the principles of material selection, separation, isolation, detection, and control. These principles involve separating the three contributory factors to a fire (fuel, ignition source, and oxygen), isolating potential fires from spreading to other parts of the airplane, and controlling a fire should one occur. Boeing uses both passive systems (such as the use of noncombustible or self-extinguishing materials) and active systems (such as fire extinguishing systems). Fire protection features on Boeing airplanes meet all aviation regulatory requirements as well as internal Boeing design requirements.

This article describes how Boeing incorporates fire protection features and materials into the airplane cabin that meet or exceed fire protection standards defined by U.S. Federal Aviation Regulations (FAR).

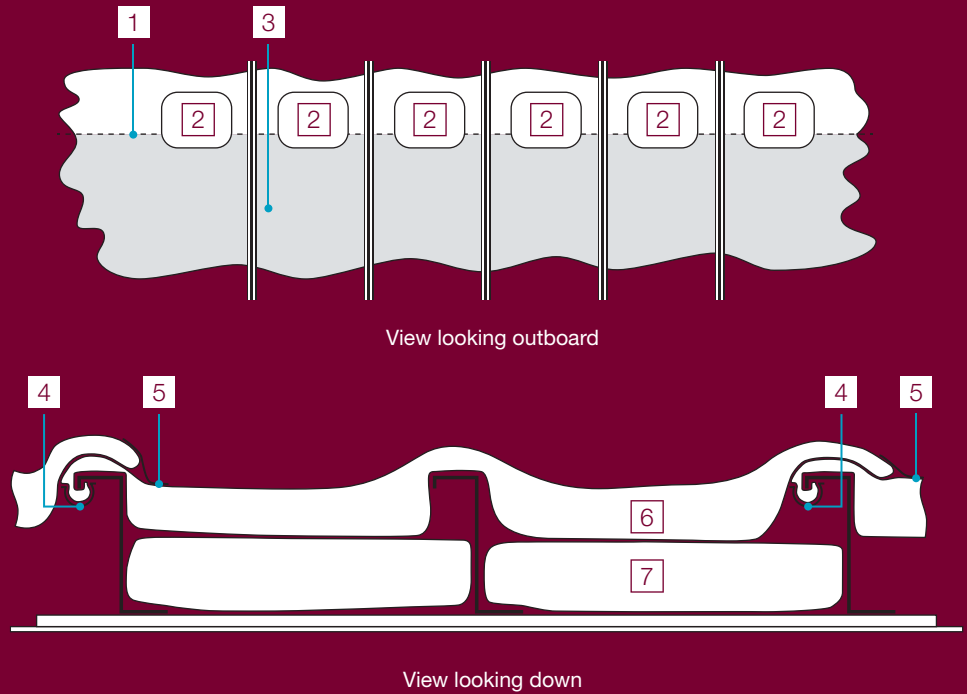
FIRE-PROTECTIVE MATERIALS

Most materials used in the construction of passenger compartment interiors are required by the U.S. Federal Aviation Administration (FAA) to be self-extinguishing (i.e., stop burning after the flame source has been removed) or better. For example, electrical wire and cable insulation must be self-extinguishing.

Figure 1: Insulation blanket burn-through protection

Fire-protective insulation blankets are designed to resist burn-through from a fuel fire next to the bottom half of the fuselage.

- 1 Halfway Line
- 2 Windows
- 3 Insulation
- 4 Steel Clip
- 5 Tape
- 6 Overframe Blanket
- 7 Between-Frame Blanket



Interior components of Boeing airplanes meet flammability requirements prescribed in Title 14 Code of Federal Regulations (CFR) Part 25. These components include:

- Interior ceiling.
- Interior sidewall panels.
- Partitions.
- Galley surfaces and structure.
- Exposed surfaces of stowed galley carts and standard galley containers.
- Large cabinets and cabin stowage compartments.
- Passenger seat material.

For materials in areas not covered by the CFR requirements, Boeing design guidelines are used to identify additional flammability, smoke, and toxicity requirements.

The standards for flammability of insulation blankets have improved over time. A recent requirement change calls for the enhancement of the fire-protective features of insulation blankets in the event of an in-flight or post-crash fire. The latest standard increases protection by minimizing the

contribution of the insulation blankets to the propagation of a fire. Thermal/acoustic insulation installed behind cabin interior panels with the appropriate fire-resistant properties can delay the onset of fire into the cabin in the event of a crash (see fig. 1). The insulation blankets, along with the airplane skin, must be capable of resisting burn-through from a fuel-fed post-crash fire next to the bottom half of the fuselage for a minimum of four minutes to allow passengers to evacuate the airplane before burn-through can occur.

ISOLATION AND SEPARATION CONTROLS

Boeing reviews the overall design of the airplane at a systems level to further enhance airplane safety. This includes the following based on established Boeing design guidelines:

- Identify potential ignition sources.
- Identify failure modes to ensure ignition sources are minimized.

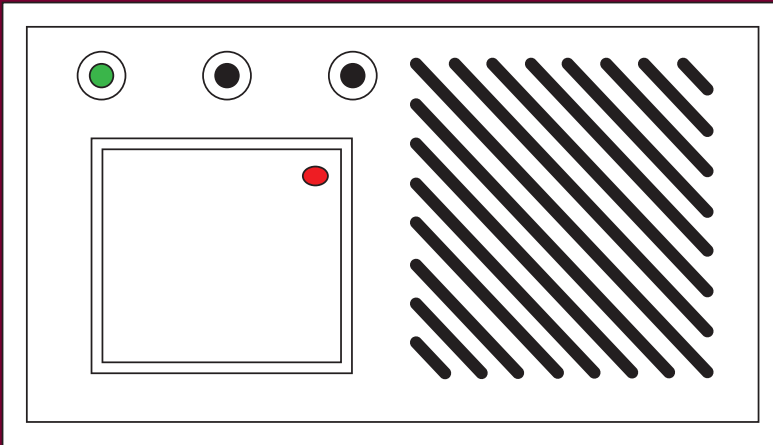
- Establish design features to minimize potential ignitions.
- Establish design features to isolate potential ignition sources from combustibles (e.g., electrical shutoff switches for in-flight entertainment systems).
- Establish design features to contain or localize potential fires, including arrangement, materials, and ventilation. Examples include galley trash compartments, fire stops behind monuments, and sidewalls.

FIRE DETECTION

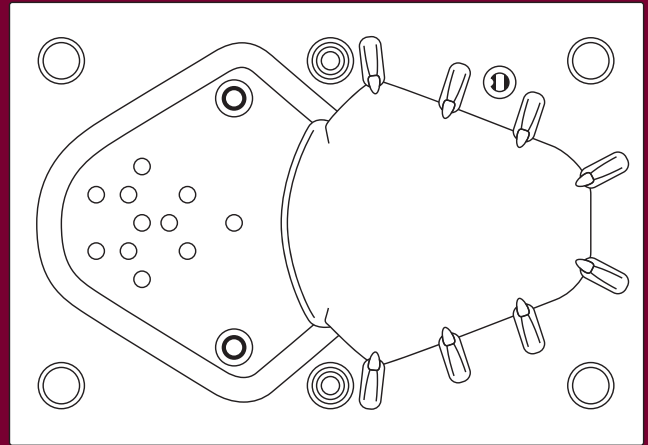
Three types of smoke detectors are certified for use in the lavatories and crew rest compartments, as well as in some galley complexes, purser work stations, video control centers, and business centers: ionization-area type, photoelectric-area type, and photoelectric-ducted type. A dedicated smoke detection system is not required in the occupied volumes of the main cabin due to the ability of passengers and the cabin crew to recognize smoke.

Figure 2: Ceiling-mounted smoke detectors

Typical faceplate of a ceiling-mounted ionization smoke detector (left) and a photoelectric smoke detector (right).



Ionization smoke detector



Photoelectric smoke detector

Ionization-area type. These detectors are designed to detect the presence of ionized particles created by the combustion process as they are convectively carried through the lavatories or crew rest compartments in the event of a fire. They are typically mounted in the ceiling or upper sidewalls of the protected space (see fig. 2).

Photoelectric-area type. These detectors are designed to detect the presence of smoke particles in the air by reflection of scattered light. They also rely on particles in the air being convectively carried into a sensing chamber where light from a pilot lamp is transmitted through a sensing chamber. If smoke is present, it will reflect light onto a photocell and trigger an alarm. Newer production airplanes use photoelectric detectors based on an advanced smoke sensor utilizing two discrete wavelengths to determine the presence of smoke and to distinguish between smoke and nonsmoke aerosols. These are also mounted in the ceiling or upper sidewalls of the protected space.

Photoelectric-ducted type. These detectors are similar to photoelectric-area type detectors, but they are typically mounted behind the walls of the protected space. They differ from the area detectors in that fans draw air samples from the protected space into a series of air sampling ports in the monument walls and ceiling, and then through an aluminum tube manifold to the detectors. Current production airplanes use the more advanced area detectors mentioned above, rather than ducted photoelectric detectors.

Each smoke detection system has a built-in electronic test capability switch. This allows for the system's electrical and detector sensor integrity to be checked at any time.

Detection of smoke is affected by compartment volume and contour, air distribution, and the amount and buoyancy of the combustion particles. Boeing conducts extensive laboratory and flight testing to determine the best location for the detector sensors to enable them to most effectively detect smoke under all conditions.

CONTROL OF FIRES

Handheld fire extinguishers are provided throughout the airplane cabin for manual firefighting. Boeing airplanes currently use water or Halon 1211 fire extinguishers. Boeing is working on a replacement for halon extinguishers, but it is not yet available. (For an in-depth discussion on halon, see page 13.)

Halon 1211 fire extinguishers have a minimum Underwriters Laboratories rating of 5B:C. This type of extinguisher contains approximately 2.5 pounds (1 kilogram) of Halon 1211, weighs about 4 pounds (1.8 kilograms), and can be used on any fire likely to occur in the airplane, including paper, fabric, electrical, or flammable fluids. Halon 1211 extinguishers have also been successful in extinguishing fires behind the sidewall panels.

Water fire extinguishers have FAA technical standard order (TSO)-C19c certification approval. These units are intended to combat fires involving combustible materials such as paper and textiles.

Figure 3: Typical fire extinguisher locations

Fire extinguishers are located throughout the passenger cabin with locations designed for easy access in an emergency.

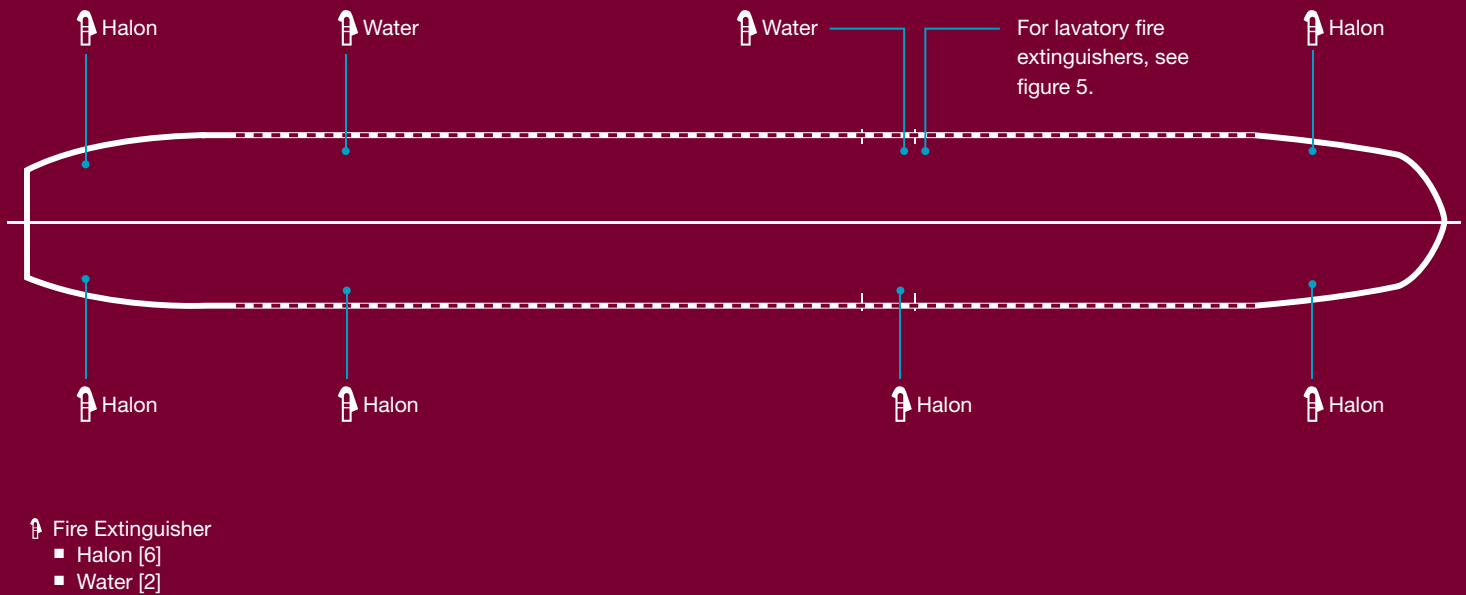


Figure 4: Distribution of handheld fire extinguishers

The number of handheld fire extinguishers on passenger airplanes is determined by the airplane's passenger capacity.

Airplane Passenger Capacity	Number of Extinguishers
61–200	3
201–300	4
301–400	5
401–500	6
501–600	7
601–700	8

Halon 1211 or equivalent fire extinguishers are spaced throughout the cabin and easily accessible from the aisle or entryway. A water fire extinguisher is typically located near a lavatory-galley complex. In some cases, one or more Halon 1211 extinguishers are used in place of the water fire extinguisher.

FIRE EXTINGUISHER LOCATIONS

Both halon and water fire extinguishers are located throughout the passenger cabin (i.e., each passenger compartment separated by doors or stairways) (see fig. 3). The minimum number of extinguishers is based on the airplane's passenger capacity (see fig. 4).

Galley complex. A Halon 1211 or equivalent fire extinguisher is generally located within 8 feet (2.4 meters) of each galley complex.

Flight deck. A Halon 1211 or equivalent extinguisher is placed for easy access by the flight crew.

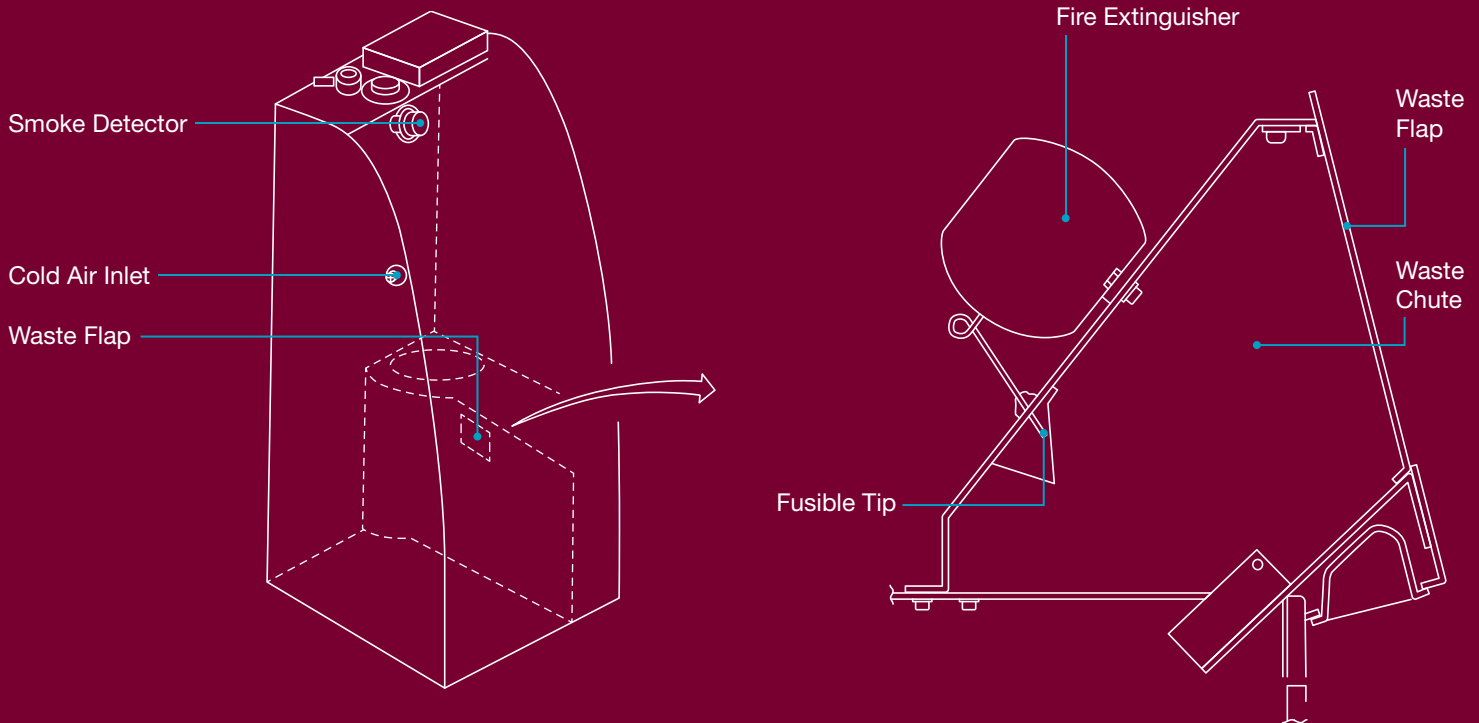
Crew/attendant rest compartments, purser work stations, video control centers, and business centers. At least one Halon 1211 or equivalent fire extinguisher is generally located within 8 feet (2.4 meters) of the compartment.

Lavatories. Each lavatory is equipped with fire protection systems designed to detect and extinguish fires and to prevent hazardous quantities of smoke from entering occupied areas (see fig. 5). Lavatory fire-protection features include:

- A smoke detection system that provides a warning light on the flight deck, or provides a warning light or audible warning in the passenger cabin that would be readily detected by a flight attendant.
- Each receptacle used for the disposal of flammable waste material is fully enclosed, constructed of fire-resistant materials, and able to contain fires that might occur.
- Boeing requires that all current production lavatories be capable of containing a fire for 30 minutes.

Figure 5: Lavatory fire protection

Lavatories include systems to both detect and extinguish fires.



Note: Installation of the items shown varies by airplane model.

- A built-in fire extinguisher for each paper waste disposal receptacle located within the lavatory. The extinguisher is designed to discharge automatically into each disposal receptacle upon occurrence of a fire in that receptacle. All Boeing lavatories incorporated the use of Halon 1301 as the suppression agent in fire extinguishers. On Boeing production airplanes, beginning with the 777 in April 2006, these extinguishers were replaced with FM-200 (HFC-227ea). All built-in fire extinguishers meet these FAA requirements:
 - No extinguishing agent that is likely to enter personnel compartments can be hazardous to the occupants.
 - No discharge of the extinguisher can cause structural damage.
 - The capacity of each extinguishing system must be adequate for any fire likely to occur in the compartment where used, considering the volume of the compartment and the ventilation rate.


Crew rest compartment. A smoke detection system that consists of ceiling- and/or sidewall-mounted smoke detectors and associated control hardware and alarms is incorporated into crew rest compartments. Crew rest compartments are also designed to prevent hazardous quantities of smoke from entering flight crew or passenger areas.

When smoke is detected by the smoke detection system, appropriate audio and visual alarms provide indication on the flight deck, in the crew rest compartment, and in the nearby cabin areas. For larger crew rest compartments, the air distribution system's air shutoff valve closes, preventing air-conditioning flow to the crew rest compartment to better contain smoke and facilitate crew firefighting procedures. In many instances, a minimal exhaust flow is maintained to assist in preventing smoke penetration into occupied areas and maintain visibility.

Firefighting procedures for crew rest compartments usually involve one or more members of the cabin crew using appropriate protective equipment to manually suppress the fire with a handheld fire extinguisher. In some cases, such as the 777 lower lobe attendant rest compartment, the fire is suppressed remotely by using a built-in halon fire-extinguishing system plumbed to the compartment.

SUMMARY

Boeing uses a comprehensive systems-level approach in airplane cabin design to minimize the potential for a fire and to help ensure the safety of passengers.

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Operators may need to retrofit their airplanes to ensure existing fleets are properly equipped for RNP operations.

Equipping a Fleet for Required Navigation Performance

Required navigation performance (RNP) is the global benchmark for all future aviation navigation. Operators need a properly equipped fleet to receive RNP operational approval and take advantage of the benefits offered by RNP operations.

By Dan Ellis, Avionics Design Engineer, Flight Management Systems;

Gary Limesand, Model Focal, Flight Deck/Crew Operations; and

Bill Syblon, Flight Operations Specialist, Modification Services

RNP operations can improve the safety, capacity, efficiency, access, and environmental impact of the greater airspace system, providing real economic benefits for RNP operators. RNP also is the foundation to evolving ATM operations and establishes a basis for global interoperability. Operators must understand the airplane equipment requirements for RNP operations in order to determine what level of capability and operational approval will offer them the greatest benefit.

This article provides a standardized equipment configuration for each model, suitable for all RNP applications. It also explains concepts surrounding RNP and explores existing RNP standards.

REQUIRED NAVIGATION PERFORMANCE DEFINED

RNP is a statement of the navigation performance necessary for operation within a defined airspace. Specifically, RNP can be visualized as the requirement to keep the actual airplane position within a specified radius for a given percentage of the time. RNP is formally defined by four main terms:

Accuracy: The requirement to keep the actual airplane position within a radius that is 1xRNP for 95 percent of the time.

Integrity: The requirement to keep the actual airplane position within a radius that is 2xRNP for 99.999 percent of the time.

Availability: The probability, using general risk, that the navigation service (e.g., global positioning system [GPS], distance measuring equipment [DME] infrastructure) providing the required accuracy and integrity will be present during the intended operation.

Continuity: The probability, using specific risk, that the navigation system (e.g., flight management system [FMS] and other equipment) will provide the required accuracy and integrity during the intended operation.

The required level of availability and continuity for a given route or procedure is established by the regulator and optionally improved upon by the operator. Figure 1 provides an example of a Boeing analysis for generalized availability while GPS

Figure 1: Example of worldwide navigation availability for selected required navigation performance (RNP) with GPS updating

The availability of an RNP operation varies depending on the number of satellites operating in the global positioning system (GPS) constellation. For example, this table shows that general availability for an RNP 0.3-nmi operation is 99.98 percent when there are 24 satellites operating. This means the required accuracy and integrity will be unavailable one out of every 5,000 attempts. Operators can use estimates like this to evaluate whether the benefits of performing the intended operation outweigh the challenges posed by the given availability. Operators should refer to the applicable RNP capabilities document for the specific availability values for their fleet.

Number of Satellites in GPS Constellation	Availability RNP 10 nmi	Availability RNP 4 nmi	Availability RNP 2 nmi	Availability RNP 1 nmi	Availability RNP 0.5 nmi	Availability RNP 0.3 nmi	Availability RNP 0.15 nmi
24	>99.999%	>99.999%	>99.999%	>99.999%	99.99%	99.98%	99.62%
23	>99.999%	>99.999%	>99.999%	99.98%	99.87%	99.67%	97.76%
22	>99.999%	99.99%	99.99%	99.82%	99.30%	98.61%	94.29%
21	>99.999%	99.96%	99.89%	99.33%	98.10%	96.60%	89.34%

Figure 2: Performance-based navigation standards

Required navigation performance (RNP) and area navigation (RNAV) are both part of performance-based navigation, a framework for defining navigation performance requirements that can be applied to an air traffic route, instrument procedure, or defined airspace.

Area Navigation (RNAV)



RNP10
Oceanic
Remote

RNAV5
RNAV2
RNAV1
Route
Terminal

Required Navigation Performance (RNP)



RNP4
Oceanic
Remote

Basic-RNP1
RNP Approach
RNP
Authorization
Required Approach
Various Phases

RNP
Additional
Requirement
3D & 4D

Figure 3: Required navigation performance (RNP) and area navigation (RNAV) standards*

Navigational Specification	Area of Application	Navigational Accuracy (nmi)	Applicable Regulatory Document	
			Federal Aviation Administration	European Aviation Safety Agency/Joint Aviation Authorities
RNP Authorization Required	Terminal and Approach	≤0.3	AC 90-101A	AMC 20-26
RNP Approach	Approach	0.3	AC 90-105	AMC 20-27
RNAV 1	Terminal and En Route	1	AC 90-100A	TGL-10/AMC 20-16
RNAV 2	Terminal and En Route	2	AC 90-100A	N/A
RNAV 5	Terminal and En Route	5	N/A	AMC 20-4
RNP 4	Oceanic and Remote	4	Order 8400.33	N/A
RNP 10	Oceanic and Remote	10	Order 8400.12b	AMC 20-12

* The FAA and EASA standards have not been completely harmonized.

updating. Route- and region-specific analysis tools are available outside Boeing and may yield different results.

Actual navigation performance (ANP) represents the current 95 percent accuracy of the Boeing FMS position. ANP and RNP are displayed in nautical miles on the navigation displays and the control and display units.

When ANP exceeds RNP, an UNABLE RNP message is displayed to the flight crew. This indicates that the FMS position does not meet the required accuracy, so the procedure (such as an approach) must be aborted.

RNP IN AIR TRAFFIC CONTROL

RNP is a key component of the basic air-traffic services triad of communication, navigation, and surveillance (or monitoring) that is required for a safe and efficient airspace system.

RNP is a subset of performance-based navigation (PBN), which also includes area navigation (RNAV) (see fig. 2). (For an explanation of RNAV, see *AERO* second-quarter 2008.)

As air traffic management (ATM) operations in the world evolve, there is an increasing dependence on RNP operations as a foundation for improvements in airspace design and management, safety, operational efficiencies, and environmental improvements. Many states have begun to

implement changes in their ATM systems, and more are expected. These changes will allow airlines with RNP-capable airplanes to derive value from their existing capabilities. As the new ATM environments grow, providing more opportunities for operational efficiencies, it is expected that such benefits will offset the cost of equipment changes for airplanes.

BENEFITS TO AIRLINES, AIRPORT AUTHORITIES, AND COMMUNITIES

RNP allows airlines to use safer and more efficient flight paths that will enable a variety of possible benefits, including airspace efficiency through reduced separation, reduced fuel burn/emissions from shorter flight paths, and improved runway access from lower minima. RNP can be used in conjunction with RNAV or even with an instrument landing system (ILS) or global navigation satellite system landing system (GLS). RNP allows for better transition routes to these landing systems and better accommodation of missed approach paths.

The RNP concept enables airlines to gain efficiency by optimizing the use of available airspace, enabling reductions in aircraft separation, and enabling shorter routes by not being constrained by overflight of ground navigational-aid locations. RNP also allows for better use of all other airspace, such as oceanic and remote areas.

A fixed lateral flight path also affords better energy management and quieter climbs (i.e., up and away quicker at best climb gradient via a more direct path) and descents (i.e., idle or near-idle). Finally, RNP enables airlines to precisely control what their airplanes are flying over, such as avoiding noise-sensitive areas.

In the future, use of RNP routes and procedures is likely to be the best way to efficiently and cost-effectively accommodate and coordinate the various demands of all airspace users globally, from transports and unmanned aerial vehicles, to business and sport aviation, to security and military uses of airspace.

Increased application of RNP instrument procedures will allow for better use of multiple airport runway configurations for increased airport capacity.

QUALIFYING FOR RNP OPERATIONS

To perform RNP operations, operators must apply for and receive operational approval from the applicable regulator. It is not enough for an operator to simply purchase and enable the RNP options in their fleet and confirm the airplane flight manual–demonstrated RNP supports the intended operation. Instead, operators must equip their fleets and establish appropriate procedures, documentation, and training as specified in the regulator’s published

Figure 4: 737-600/-700/-800/-900: Standardized equipment configuration

Required configurations for other Boeing models are available in the online version of this article (see www.boeing.com/commercial/aeromagazine).

U.S. Federal Aviation Administration and European Aviation Safety Agency Requirements

RNP Capability — Required Hardware/Features	<ul style="list-style-type: none"> Multi-mode receivers (included in basic airplane configuration)
RNP AR 0.30 nmi Final and 1.0 nmi Missed Approach	<ul style="list-style-type: none"> Speed and altitude intervention activation (Boeing recommendation). Two flight management computers (FMCs) (dual).
RNP AR <0.30 nmi Final and/or <1.0 nmi Missed Approach	<ul style="list-style-type: none"> Captain's FMC, multipurpose control and display unit (MCDU), and inboard display unit on standby power. Default distance measuring equipment (DME) update to off (if required by procedure). Navigation performance scales (airplane flight manual RNP 0.10). <ul style="list-style-type: none"> 737-3C data frame software update to digital flight data acquisition unit. Common display system (CDS) operational software (OPS) 2004A software or later. Takeoff/go-around (TOGA) to lateral navigation (LNAV) go-around. <ul style="list-style-type: none"> Flight control computer 710 or P3.0 software or later. CDS OPS 2004A software or later. FMC U10.6 software or later.

RNP standard as part of the application process (see fig. 3).

Boeing provides full services around the world to completely equip and train operators for RNP operations. Additionally, Boeing completes applications for operational approval to qualify operators to become RNP certified through their regulators.

RNP STANDARDS

Existing and upcoming RNP standards will increasingly leverage RNP-capable systems in order to derive additional airspace system benefits (e.g., any one or all of capacity, efficiency, safety, or access). The current set of possible RNAV and RNP operations has differing equipage requirements. Before determining which type of RNP operations to equip for, airlines must understand their operational needs — including the primary level of operations and what level is acceptable for contingency operations at destinations served and planned.

The standards for each level of RNP are defined by various regulators, including the U.S. Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) (see fig. 3). The FAA and EASA have slightly different definitions of what constitutes an RNP-capable system.

EQUIPPING AN EXISTING FLEET FOR RNP OPERATIONS

Boeing has defined the specific equipment requirements for each of its commercial airplane models that are available for RNP equipage retrofit: 737-300/-400/-500, Next-Generation 737, 757, 767, 747-400, 777, MD-10, MD-11, 717, MD-80, and MD-90. Figure 4 provides one example, listing the RNP AR equipage requirements for a Next-Generation 737.

While specific airplane equipment requirements must be met for each level of operational approval, Boeing has defined a minimum demonstrated RNP for each airplane model.

RNP EQUIPAGE RETROFITTING AND OPERATIONAL APPROVAL SERVICES FROM BOEING

Boeing provides an integrated RNP retrofitting and operational approval program. Boeing works with operators to identify the markets and airplanes in their fleets that will offer the greatest return on their RNP capability investment and then manages all phases of the implementation process. This includes:

- Designing and validating RNP procedures.
- Establishing operational specifications and operations manual revisions, as required by the airline.

- Identifying and managing suppliers and contractor services.
- Instituting the rigorous navigation data services necessary for RNP operations and regulatory approval.
- Developing avionics configuration recommendations to support fleet RNP capabilities and providing a modification kit, if required.
- Providing flight crew and dispatcher training, if required.
- Supporting airlines in gaining regulatory approval for RNP operations.

SUMMARY

Depending on the types of intended operations and the evolving nature of air traffic operations globally, retrofitting an operator's existing fleet for RNP operations may be required. Boeing is prepared to support RNP implementation by guiding operators through the entire retrofit and operational approval process.

For more information, please contact Boeing Modification Services at modservices@boeing.com. **A**

